

(12) **United States Patent**
Levine et al.

(10) **Patent No.:** US 6,389,101 B1
(45) **Date of Patent:** May 14, 2002

(54) **PARALLEL X-RAY NANOTOMOGRAPHY**

- (75) Inventors: **Zachary H. Levine**, Rockville, MD (US); **I. C. Edmond Turcu**, Del Mar, CA (US)
- (73) Assignee: **JMAR Research, Inc.**, Santa Clara, CA (US)
- (*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **09/578,115**

(22) Filed: **May 24, 2000**

Related U.S. Application Data

- (60) Provisional application No. 60/135,639, filed on May 24, 1999.
- (51) **Int. Cl.**⁷ **G21K 1/06**
- (52) **U.S. Cl.** **378/85; 378/145**
- (58) **Field of Search** 378/21, 22, 25, 378/34, 84, 85, 145; 359/558, 559, 562

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,883,698 A	11/1989	Bothe et al.
5,003,779 A	4/1991	Goldstein
5,089,711 A	2/1992	Morsell et al.
5,263,073 A	11/1993	Feldman
5,434,875 A	7/1995	Rieger et al.
5,491,707 A	2/1996	Rieger et al.
5,497,008 A	3/1996	Kumakhov
5,539,764 A	7/1996	Shields et al.
5,550,887 A	8/1996	Schmal et al.
5,654,998 A	8/1997	Turcu et al.
5,790,574 A	8/1998	Rieger et al.

OTHER PUBLICATIONS

Janos Kirz et al., "Soft X-ray microscopes and their biological applications," 28 Quarterly Reviews of Biophysics 33-130 (1995).

J. Lehr, "3D X-ray microscopy: Tomographic imaging of mineral sheaths of bacteria *Leptothrix Ochracea* with the Gottingen x-ray microscope at BESSY," *Optik*, vol. 104, No. 4, pp. 166-170 (1997).

P. Dehz et al., "Instrumental aspects of x-ray microbeams in the range above 1 keV," *Review of Scientific Instruments*, vol. 70, No. 4, pp. 1907-1920 (Apr. 1999).

G.T. Herman, *Image Reconstruction from Projections: the Fundamentals of Computerized Tomography*, pp. 108-117 (1980).

Levine et al., "Tomographic reconstruction of an integrated circuit interconnect," *Applied Physics Letters*, vol. 74, No. 1, pp. 150-152 (Jan. 4, 1999).

Nakamaya et al., "Zone-Plate X-Ray Microscope Using a Laser Plasma Source," *Japan J. App. Phys.*, vol. 33, Part 2, No. 9A, pp. 1280-1282 (Sep. 1, 1994).

A.C. Kak et al., *Principles of Computerized Tomographic Imaging*, pp. 60-75 (1986).

P. Guttman et al., "X-Ray Microscopy Studies With the Gottingen X-Ray Microscopes," 1741 *SPIE* 52-61 (1992).

W.S. Haddad et al., "Ultrahigh-Resolution X-ray Tomography," *Science*, vol. 266, pp. 1213-1215 (Nov. 18, 1994).

Norio Watanabe et al., "Three-dimensional tomography using a soft X-ray holographic microscope and CCD camera," 5 *J. Synchrotron Rad.* 1088-1089 (1998).

I.C.E. Turcu et al., *X-Rays from Laser Plasmas*, pp. 50-58 (1999).

Primary Examiner—David P. Porta

(74) *Attorney, Agent, or Firm*—William D. McSpadden; Baker & McKenzie

(57) **ABSTRACT**

A parallel nanotomography imaging system is provided having an x-ray source, which is preferably a laser-based x-ray source that generates x-rays that are collected using a collector optic and are received in a composite objective assembly. The composite objective assembly includes plural micro-objectives, each imaging the target. The x-ray image is received by an x-ray image formation and acquisition apparatus, and processed and/or displayed.

32 Claims, 8 Drawing Sheets

